U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: Turbojet, Turboprop, and Turbofan Engine Induction System Icing

Date:

Initiated By: AIR-100

AC No: DRAFT 20.xx

Change:

1. PURPOSE. This advisory circular (AC) provides guidance and acceptable methods, but not the only methods, that may be used to demonstrate compliance with the applicable induction system icing and ice ingestion requirements of parts 25 and 33 of the Federal Aviation Regulations, under (14 CFR parts 25 and 33). The primary purpose of this AC is to reduce inconsistencies and eventual surprises to both engine manufacturers and engine installers when installing a part 33 certified engine in a part 25 aircraft. The guidance in this AC is not intended to cover turboshaft engine installations or the rotary wing aircraft they are installed on due to the complexity those aircraft and installations pose for icing. Part 23 airplane installations are also not directly addressed by this AC. Further, this AC is not intended to address mixed phase icing conditions (i.e., mixed water and ice precipitation), although there is a discussion on the subject. Falling and blowing snow

conditions will likely be the subject of a future AC. Like all AC material, this AC is not, in itself, mandatory and does not constitute a regulation. While these guidelines are not mandatory, they are derived from extensive Federal Aviation Administration (FAA) and industry experience in determining compliance with the pertinent regulations.

2. RELATED REGULATIONS.

a. Part 25, Airworthiness Standards: Transport Category Airplanes, §§ 25.1093 and 25.1419.

b. Part 33, Airworthiness Standards: Aircraft Engines, §§ 33.68, 33.77(c), 33.77(e), and 33.89(b).

3. RELATED READING MATERIAL.

a. AC 20-73, Aircraft Ice Protection (dated 4-21-71).

b. AC 33-2B, Aircraft Engine Type Certification Handbook (dated 6-30-93).

c. AC 25.939-1, Evaluating Turbine Engine Operating Characteristics.

d. FAA Report No. FAA-RD-77-78, Engineering Summary of Powerplant Icing Technical Data, July 1977.

4. BACKGROUND.

a. The induction system icing requirements of parts 33 and 25 are intended to provide protection for anticipated flight into icing conditions with no adverse effect on engine operation or serious loss of power or thrust. Propulsion systems certified under these requirements and operated in accordance with the airplane flight manual have generally demonstrated safe operation when exposed to natural icing environments. The current guidance material contained in AC 20-73 and AC 33-2B is still valid and useful except as specifically noted throughout sections of this AC. This AC supplements previously published guidance addressing critical certification conditions for the engine that may occur within the part 25, Appendix C icing envelope. It is anticipated that potential in-service encounters that are found to be outside of part 25, Appendix C, will be addressed separately from this AC. The suggested test conditions called out in section 33(b) of AC 20-73 and in Table 1-1 of this AC are intended to be standard engine test conditions. These standard conditions should be used unless the engine manufacturer determines other conditions are more critical. These standard test conditions are, in some cases, outside of part 25, Appendix C conditions, but have been determined to provide an adequate and consistent basis for engine icing certification. The additional margin demonstrated by successful operation at conditions that are outside of the part 25, Appendix C icing envelope is intended to address the potential myriad of engine power conditions, aircraft flight conditions, and environmental conditions that could prove too difficult to realistically test.

b. Although this AC does not directly address part 23 airplane installations, § 23.1093 dealing with turbine engine installation is materially identical to § 25.1093 dealing with turbine engine installations.

5. DEFINITIONS. The following are defined for the purpose of this AC.

a. Auto-recovery systems. Auto-recovery systems typically include auto-relight systems, stall recovery systems, or any other engine system intended to recover the operability of an engine following a flameout, surge, or stall.

b. Freezing fraction. The fraction of impinging water that freezes on impact.

c. Ice formations. Ice formations resulting from the impact of supercooled water droplets on propulsion system surfaces are classified as follows:

(1) Glaze ice. A clear, hard ice that forms at temperatures close to (but below) freezing, with high liquid water content and large droplet sizes. Droplets impacting the surface do not freeze immediately, but run back along the surface until freezing occurs.

(2) Rime ice. A milky, white ice that forms at low temperatures, with low liquid water content and small droplet sizes. This ice is similar to the deposits found on refrigerator coils.

(3) Mixed or intermediate ice. A combination of glaze and rime ice that forms with rime patches slightly aft of the glaze ice portions. This ice forms at temperatures, liquid water content, and droplet sizes between those that produce rime and glaze ice.

d. Ice shed cycles. The time period required to buildup and shed an ice accretion on a propulsion system surface for a given power and icing condition.

e. Icing condition. A meteorological condition defined by the following parameters:

(1) Liquid Water Content (LWC). Concentration of liquid water in air, typically expressed in grams of water per cubic meter of air.

(2) Mean effective droplet diameter (MED). A characteristic of a given icing cloud where the volume of water associated with droplets larger than the MED is equal to the volume of water associated with droplets smaller than the MED.

(3) Temperature. The total temperature associated with the icing cloud environment.

f. Mild operability effects. Similar to the definition found in AC 25.939-1. Includes minor compressor stalls; light, almost imperceptible surges; no perceived power loss; no engine damage; and immediate return to normal operation. Engine operating instability is brief and of minor intensity, and crew action is not required.

g. Power loss instabilities. Engine operating anomalies such as non-recoverable rollback, surge, stall, or flameout, that can result in engine power or thrust cycling.

h. Scoop factor (concentration factor). The ratio of nacelle inlet highlight area (A_H) to the area of the captured air stream tube (A_C) [Scoop Factor = A_H/A_C]. The highlight area is defined as the area bounded by the leading edge of the nacelle inlet.

i. Sustained power loss. A permanent reduction in power or thrust at the engine's primary power set parameter (e.g., fan rotor speed, engine pressure ratio). Power or thrust losses that are not sustained are those that are temporary in nature and may be related to the effects of icing.

j. Water impingement rate. The rate (gm/Sq. m/min) at which a portion of the surface area of a solid object is impacted by the water droplets in a moving air stream.

6. DISCUSSION. The induction system icing requirements of §§ 33.68 and 25.1093 are intended protection for flight into known icing conditions with no adverse effect on engine operation or sustained loss of power. An icing encounter should not be of consequence to the crew and it should not invalidate the engine's compliance with any other part 33 requirement. The engine should have sufficient durability to operate through repeated environmental encounters, such as icing, without special operational or maintenance intervention. Operational procedures to assist ice shedding, such as throttle manipulation, should not be relied upon or be required to comply with parts 25 and 33 in flight icing requirements. The applicant should provide instrumentation and photographic coverage to supplement test results obtained under §§ 33.68 and 25.1093. Close coordination is necessary by all parties to ensure that test plans are within reasonable bounds for the anticipated use of the airplane. The body of this AC is arranged in three sections corresponding to the applicable sections of the Federal Aviation Regulations (§§ 33.68 and 33.89(b); 33.77; and 25.1093).

a. Mixed Phase or Glaciated Icing Conditions. Mixed phase icing conditions occur when supercooled liquid water droplets and ice particles coexist in a cloud, often around the outskirts of a thunderhead cloud formation. Service experience generally indicates that turbine engines are not susceptible to mixed phase or glaciated icing conditions, with the exception of two known vulnerable engine design features. These two design features are (1) pronounced inlet bends (such as particle separator inlets) or inlet flow reversals, where inlet flow can stagnate and accrete ice, and (2) high solidity dual row front stage compressor stators that can be susceptible to non-aerodynamic ice buildup on the stator air foils resulting in core airflow blockage. These two design features should either be avoided or carefully scrutinized by analysis and testing to assure their non-susceptibility to mixed phase or glaciated icing conditions.

b. Auto-recovery systems. The use of auto-recovery systems is acceptable for certain engine certification testing. The FAA supports the use of auto-recovery systems, or other protective engine systems or devices, while in service, and allows the use of auto-recovery systems during ice slab ingestion certification testing as defined in § 33.77. Generally, compliance with §§ 33.68 and 33.77 requires a demonstration that no sustained flameout, sustained power loss, or unrecoverable surge or stall or rundown is evident. Although ignition systems have generally been found to be acceptably reliable for auto-relight use after certain ice ingestion or accretion induced flameouts (e.g., § 33.77), the auto-relight system should not be relied on during typical icing encounters (e.g., §33.68). Auto-recovery systems are considered to be back-up devices that are only needed following rare ice ingestion events resulting from severe (outside part 25, Appendix C) icing conditions, and not the primary protection for continued safe engine operation during normal ice sheds or accretion while operating in typical icing conditions. Details will be provided later in this AC relative to the use of auto-recovery systems when demonstrating compliance with §§ 33.68 and 33.77.

SECTION 1. INDUCTION SYSTEM ICING (§§ 33.68 and 33.89(b))

7. DESIGN ANALYSIS. Compliance with the requirements of § 33.68 includes identifying, through design analysis, the critical operating points for icing within the declared operating envelope of the engine. The design analysis should encompass the range of possible combinations of icing condition and engine power. The design analysis should be validated to some degree by empirical test data. Often the critical point analysis is supplemented with development test data (e.g., wet and dry testing with thermocoupled components). The methodology used to calculate ice accretions should account for pertinent aerodynamic effects (e.g., water ingestion into fan inlet and core inlet (scoop factors), water impingement rates for critical surfaces) in conjunction with an energy balance of critical engine surfaces. For anti-iced parts, the design point should be determined from energy balance calculations of required heat loads encompassing the range of possible combinations of icing condition and engine power. In instances of low freezing fraction, additional complexities arise from assessing the effects of non-aerodynamic ice formations and their shedding. FAA Report No. FAA-RD-77-78, Engineering Summary of Powerplant Icing Technical Data, provides additional guidance on performing a design icing analysis. The design analysis should address, at minimum, the following icing issues:

a. Ice shed damage. Ice accretion on engine surfaces (e.g., blades, vanes, sensors, etc.) will eventually shed. The shed ice can subsequently cause engine damage if it impacts an engine surface with sufficient mass and velocity.

(1) Fan module. Acoustic panels, fan rub strips, and fan blade tips are susceptible to ice shed from inlet sensor(s), spinner, and fan blade root. The effects of ice density, hardness, and adhesion strength should be assessed to realistic flight conditions. The ice shed cycle for rotating surfaces, such as fan blades, is strongly influenced by rotor speed and the adhesive strength of the ice to the surface. The adhesive strength of ice increases with decreasing surface temperature. The ice thickness and rotor speed at the time of the shed defines the impact threat. In determining the critical conditions for fan module damage, surface temperature, exposure time, and rotor speed are important considerations in addition to more typical parameters, such as icing condition and scoop factor. In particular, extended operation in a holding condition in very cold continuous maximum icing conditions will maximize the adhesion of ice on rotating fan components.

(2) Compressor damage. A common damage scenario in turbofan engines is the accretion of glaze (non-aerodynamic) ice formations on static components (e.g., sensors and bleed ducts) which when it sheds, results in damage. This type of damage generally occurs on the first blade set in the high-pressure compressor (intermediate pressure compressor for three

spool engines). Establishing the critical conditions for these glaze ice accretions requires careful consideration as they occur at specific limited conditions of low freezing fractions over a range of local mach numbers and air densities. The critical conditions may not occur during any of the power settings recommended by AC 20-73 (i.e., flight idle, 50 percent and 75 percent of maximum continuous, and takeoff or 100 percent maximum continuous, whichever is applicable).

b. Compressor rematch. Ice shed from upstream components may enter the core compressor. The presence of ice or water from melted ice in the gas path may cause the engine to assume new operating conditions (i.e., engine component cycle rematch). The engine should be capable of accelerating from minimum flight idle to takeoff power at any icing condition, without sustained power loss or instability (surge or stall). If any minor momentary instabilities (see Mild Operability Effects definition in section 5 of this AC), which are normally not noticeable to the flight crew, are detected by special high sensitivity instrumentation (e.g., kulites), then this anomalous instability should be raised to the cognizant Aircraft Certification Office.

c. Core ice blockage. Ice accretion on internal engine vanes due to the presence of mixed phase ice accretions may affect flow capacity and rematch of the engine cycle and should be considered in the critical point analysis.

d. Sensor fouling. Ice accretion and blockage of control sensors can result in erroneous pressure and temperature measurements. A power loss or power loss instability could result if these measurements are used by the engine to establish power or thrust ratings or to schedule other systems required to operate the engine (e.g., variable stator vanes). Critical sensors should be designed to operate without accreting ice sufficient to cause an erroneous measurement.

8. TEST POINT SELECTION. The icing test points selected should include the test points of AC 20-73, the test points outlined in this AC (see Table 1-1 of this AC), as well as those points identified as part of the critical point analysis. The applicant should consider pertinent service experience as well as the anticipated use of the aircraft when selecting critical icing test points. The following should be considered when constructing an icing test matrix:

a. AC 20-73. Under paragraph 33.b.(2), icing condition points 1 and 2, outline a widely bounded test matrix of environmental and engine operating conditions. This test matrix includes power settings from idle to takeoff during exposure to conditions typical of high altitude where rime ice formations occur, as well as conditions typical of low altitude where glaze ice formations often occur. The following modifications to the guidance in AC 20-73, paragraph 33.b.(2), are appropriate in order to clarify and update that guidance to be consistent with standard industry practices:

(1) The atmospheric temperatures specified in AC 20-73 should be interpreted to be total air temperatures and not ambient static temperatures;

(2) Icing condition 3 should be changed to not less than 0.3 g/m^3 LWC in the form of drops having a MED of not less than 20 microns, at a total air temperature between 15 and 30 degrees Fahrenheit while operating at ground idle for 30 minutes to be consistent with § 33.68(b) for ground idle operation; and

(3) Icing condition points 1 and 2 are normally run for 5 minutes at takeoff power, although lower power conditions may be warranted based on the results of the critical point analysis. All other power settings should be run for 10 minutes or longer if the natural ice shed cycle is not established or if the engine employs an inlet de-ice system that may have some unheated inlet surfaces.

b. Section 33.68(b). Section 33.68(b) provides an icing point, which represents a typical icing encounter during ground operation. The guidance contained within AC 33.2B with respect to snow ingestion testing is considered outdated. The effect of ingesting snow during ground operations can and should be evaluated. Service experience has demonstrated compressor damage (see paragraph 7.a.(2) of this AC) as a result of exposure to prolonged periods of falling snow during ground operation. Based on review of service events, airports have continued to operate with falling snow concentrations that are upwards of 0.3 grams/m^3. Falling and blowing snow is referenced in § 25.1093(b)(ii), and will likely be the subject of a future AC.

c. Holding phase. This test is applicable to part 33 engine components. The installed engine and aircraft inlet induction system should operate safely in a holding phase without a time limit when showing compliance with § 25.1093. The test program for turbofan and turboprop applications should include test points (e.g., icing condition and power setting) to address the effects of prolonged exposure in icing conditions typical of holding patterns. Point 1 in Table 1-1 represents an icing condition that is typically encountered on transport category airplanes. Point 2 in Table 1-1 represents an icing condition that is also specified in JAR-E. The engine and inlet should be capable of prolonged exposure to the conditions specified in Table 1-1. A 45-minute minimum test exposure followed by acceleration to takeoff power will demonstrate several ice shed cycles and will typically be sufficient to assess compliance for the engine.

Point	Total Air Temperature (Degrees Fahrenheit)		Liquid Water Content (g/m^3) [minimum]	Mean Effective Droplet Diameter (microns)
	Turbofan	Turboprop		
1.	-4	6	0.25	15-20
2.	14	6	0.30 6 minutes* 1.70 1 minute*	15-20 20 +/-3

Note: * alternate between these two conditions for at least 45 minutes

Table 1-1: Holding Conditions

9. TEST RESULTS AND COMPLIANCE ISSUES. During all icing tests, the engine should operate without the accumulation of ice that would adversely effect engine operation or cause a sustained loss of power or thrust. Additionally, the applicant should accurately monitor icing point conditions and provide the means to identify the source of ice damage, especially in those instances where test apparatus may shed ice (e.g., icing nozzles, special test instrumentation, etc.).

a. Sustained loss of power or thrust and power loss instabilities. There should be no sustained power loss while operating at approved ratings in icing conditions. Temporary power losses below the engine power and thrust ratings selected in accordance with § 33.8 can be accepted if it is proven that there is sufficient margin against any power loss instability, such as non-recoverable rollback, surge, stall, or flameout.

b. Mechanical Damage. Damage can be accepted that takes into account the cumulative damage from repeat encounters, provided the applicant satisfies the following criteria:

(1) Continued in-service use. Any resultant damage should be shown to be acceptable for continued in-service use.

(2) Sustained power losses. There should be no resultant sustained power loss.

(3) Temporary power loss. Any resultant temporary power loss should be recorded in the installation manual.

(4) Validation basis. Analytical tools used to substantiate the criteria for determining acceptable damage should be shown to have a sufficient validation basis (e.g., engine tests, rig tests, service experience, etc.) to substantiate the accuracy of results or be shown to yield conservative results.

(5) Disposition of Damage. Disposition of damage to any engine or engine component may not be obtainable solely by comparing the damage against the maintenance manual limits.

(6) Communication of results. The Installation and Operating Manuals required by § 33.5 should provide information describing any resultant engine condition observed during engine certification icing tests. The engine manufacturer should provide a process to permit disposition of any potential damage that could occur during natural icing flight tests conducted to demonstrate compliance with § 25.1093. Also, during ground icing operation demonstration of

§ 33.68(b), if periodic engine power run-ups are necessary to minimize damage from icing, a description of the run-up requirements and the required intervals for run-up must be contained in the Operating Manual and Airworthiness Limitations Section of the Instructions for Continued Airworthiness (ICA).

c. Engine systems. It is permissible to use engine systems (i.e., automatic, engine initiated ice protection systems) to fulfill § 33.68 requirements provided that its operation is not expected to result in crew action. Examples of engine characteristics that may not be transparent to the flight crew are exhaust gas temp (EGT) fluctuations or audible surging. Additionally, any engine system required to show compliance with § 33.68 should meet the following requirements:

(1) System reliability. Demonstrate the capability of the system for reliably sensing the conditions that enable the function throughout the operating envelope;

(2) Dispatch. The function should be available for all dispatchable configurations. The system should be configured in its most critical dispatch state for certification icing tests;

(3) Electronic faults. If the system uses electronics, substantiate that the function is not lost due to any single or probable multiple electronic faults;

(4) Other environmental testing. The function should not be affected when the system and any associated electronic systems are exposed to required operating environments, including high intensity radiated fields (HIRF) and lightning; and

(5) Power requirements. For those systems that are powered solely with a dedicated engine alternator (either directly or via another engine system such as Full Authority Digital Electronic/Engine Control (FADEC)), it should be demonstrated that over the operating envelope the function (i.e., sensing and performance) is provided at the minimum certified rotor speeds.

d. Auto-recovery systems. Auto-recovery systems should not be needed during § 33.68 testing since these icing conditions are considered to be within the engine's normal operating envelope. The intent of part 33 is to certify engines that will be able to perform and operate reliably during normally encountered icing conditions. Auto-recovery systems are considered to be back-up devices that are only needed following rare ice ingestion events resulting from severe (outside part 25, Appendix C) icing conditions, and not the primary protection for continued safe engine operation during normal ice sheds or accretion while operating in typical icing conditions. Therefore, it is acceptable to perform § 33.68 compliance testing with auto-recovery systems enabled, but they should not activate throughout the § 33.68 test sequence. Additionally, continuous ignition should not be selected during § 33.68

compliance testing. To assure non-activation of an enabled auto-recovery system, it may be necessary to display an instrumented signal that monitors auto-recovery system activation. If activation monitoring can not be accomplished, then disabling of the auto-recovery system may be necessary.

e. Operating instructions. Any operating procedure (e.g., ground run-up procedures) required to ensure continued operational compliance to the ground icing condition evaluated under § 33.68(b), and the falling snow condition evaluated under § 33.89(b), should be communicated to the installer in the Operating Instructions as a requirement that should be included in the limitation section of the Airplane Flight Manual. It may be necessary to coordinate with the installer on these procedures to ensure that they can be effectively implemented in-service.

SECTION 2. ICE INGESTION (§ 33.77(c))

10. INTENT OF ICE SLAB INGESTION TEST**.** The intent of the ice ingestion test is to demonstrate that the ingestion of an ice slab, which may form after a delayed activation of induction system anti-icing, will not adversely affect engine operation. It is intended that the engine manufacturer will consider the potential installation effects of the engine induction system. Also, there should be close coordination with the installer to ensure that potential airframe ice accumulation sites that can result in ice ingestion into the engine (i.e., inboard section of wing for an aft fuselage mounted engine) are either demonstrated under § 33.77(c) or addressed under § 25.1093 (see paragraph 16.a.(2) of this AC). The induction system manufacturer or installer should assess these accumulations in accordance with § 25.1093 and provide pertinent test variables to the engine manufacturer for incorporation into a test demonstration in accordance with § 33.77.

11. TEST CONSIDERATIONS. The test demonstration should consider ice slab sizes and trajectories aimed at critical engine locations that are based on the ice accretion and shed characteristics of the induction system which is likely to be installed on the engine. Lacking such specific knowledge, the applicant may select test conditions that are typical of a condition for a representative installation in-service. If it is determined that the ice

slab size, thickness, and density are appropriate for the engine installation, these part 33 test results can be used by the airframe manufacturer to comply with the natural icing flight test requirements related to delayed activation of the induction anti-icing system.

12. TEST RESULTS. Section 33.77(c) requires that the ingestion of ice, due to delayed activation of induction system anti-icing, may not cause a sustained power or thrust loss or require the engine to be shutdown. The following criteria should be met:

a. Sustained power losses. There should be no resultant sustained power loss;

b. Engine operability. Damage should not adversely affect engine operability (i.e., should not cause surge, stall, or flameout, nor prevent transient operation or relight);

c. In-service capability. Damage should not result in a failure or a performance loss that would prevent continued safe operation for a conservative flight cycle scenario (i.e., within fly back limits or greater if appropriate testing is done to validate a continued period of in-service capability). The period of in-service capability to be demonstrated may vary with installation if the damage is not readily evident to the crew or visible on preflight inspection (e.g., tail mounted positions); and

d. Other anomalies. Damage should not result in any other anomaly (e.g., vibration) that may cause engine operating or structural limitations to be exceeded.

e. Auto-recovery systems. If during § 33.77 ice slab ingestion testing, an engine does incur a momentary flameout and auto-relight, then normally the acceptance of that test would be predicated on the inclusion of the auto-relight system as being a required part of the engines type design, and an additional dispatch criteria would be required, where both igniters must be functional prior to each dispatch. The reason for the additional dispatch criteria is to assure the ignition system's critical relight function is reliably available during the subsequent flight. The reason for the allowance of auto-recovery systems during § 33.77 certification testing is that ice accretion and shedding due to an inadvertent 2 minute delay in actuating the anti-icing system is considered to be abnormal operation where mild operability effects (see definitions section of this AC) may be accepted.

13. COMMUNICATION OF TEST RESULTS. The installation and operating instructions required by § 33.5 should provide information on the size, thickness, and density of the ice slab ingested and any effect on the engines ability to operate at the commanded powersetting or rating. The icing certification report should include information regarding trajectories, impact locations, description of any resultant damage, and any other pertinent data defining the engine's capability or response to the ice ingestion event. Additionally, if the auto-ignition system is required to comply with § 33.77(c), then the functional state of the ignition system (i.e., one igniter inoperative) becomes a limitation that needs to be communicated to the installer for compliance with the delayed activation requirements of § 25.1093.

SECTION 3. INDUCTION SYSTEM ICING PROTECTION (§ 25.1093)

14. NATURAL ICING FLIGHT TESTS. Natural icing flight tests are intended to demonstrate that each turbine engine is capable of operating throughout the flight power range of the engine (including idling) , without the accumulation of ice on the engine, inlet system components, or airframe components that would have an adverse effect on engine operation or cause a serious loss of power or thrust. Based on multiple engine natural ice damage and operability events on flight test and in-service airplanes, the FAA requires natural ice encounters for the purpose of showing compliance with § 25.1093(b)(1). Aside from the benefit of validating the engine inlet icing analysis model, there are several other key issues that the natural ice encounter addresses. These evaluations include: (1) The adequacy of the flight crew procedures for operation in icing conditions, (2) The acceptability of tactile inputs to the flight crew as the airplane responds to engine fan blade ice shedding during a variety of airplane operating conditions, (3) The performance of the engine vibration indication system as well as other engine indication systems, and (4) The confirmation that the powerplant installation as a whole (e.g., engine, inlet, anti-ice system, etc.) performs satisfactorily while in icing conditions.

a. Identification of ice source. A means should be provided to aid in identifying the source of any ice that may be ingested by the engine during the natural icing certification testing. Special attention should be given to non-representative ice accretions on flight test instrumentation probes or other surfaces forward of the engine during prolonged operation in icing conditions.

b. Icing point monitoring. The applicant should provide sufficient monitoring of icing point condition (i.e., LWC, droplet diameter, temperature) versus time to ensure that the icing encounter is representative of part 25, Appendix C conditions.

c. Compliance. Compliance with the natural ice encounter criteria should be proposed by the applicant and agreed to by the FAA prior to the test. However, typically an adequate test sequence includes three natural fan ice shed cycles at each of the following conditions (with inlet anti-ice turned "on"): descent (flight-idle), holding (power necessary to maintain level flight for a range of anticipated airplane gross weight conditions), and maximum climb, unless a more critical engine power setting exists. These encounters should be conducted at a steady state engine thrust level and although not preferred, sometimes have involved flying through the same icing cloud multiple times (lapping) in order for the fan to accumulate enough ice for a shed cycle to occur. These fan shed cycles should be due to natural ice accumulation and not induced or forced by throttle bodies during each condition. It has also been allowed for the airplane to exit the icing conditions between each fan shed cycle for the purpose of clearing any other unprotected airplane surfaces from ice. To avoid masking any adverse engine operating conditions during the natural icing encounter, the test engine's ignition system should be selected off during the icing conditions (note that this may require pulling several airplane circuit breakers to disable the test engine's auto-ignition/recovery system). Lastly, based on past experience, it is advisable that the applicants establish and gain concurrence with the FAA for engine damage criteria prior to conducting the natural ice encounter test.

15. FALLING AND BLOWING SNOW. Section 25.1093(b)(ii) requires that engines operate satisfactorily in falling and blowing snow throughout the flight power range. The effect of ingesting snow during ground operations can and should be evaluated. Service experience has demonstrated compressor damage (see paragraph 7.a.(2) of this AC) as a result of exposure to prolonged periods of falling snow during ground operation. Based on review of service events, airports have continued to operate with falling snow concentrations that are upwards of 0.3 grams/m^3. In-flight service experience has also shown that snow can shed from engine or aircraft accumulation sites and cause severe operability effects on turbine engines. Therefore, airplanes with turbine engine inlets that have plenum chambers, screens, particle separators, variable geometry, or any other feature (such as an oil cooler) that may provide a potential accumulation site for snow should be evaluated. Falling and blowing snow may be the subject of a future AC.

16. TEST RESULTS. The applicant should carefully consider all evidence of ingestion and damage to the engines and their potential sources. If damage is incurred, the possible test outcomes include:

a. Acceptable damage. The extent of damage is equivalent to or less than that incurred and accepted during engine certification testing.

(1) All systems operating normally. The extent of damage is equivalent or less than that incurred and accepted during the § 33.68 tests.

(2) Delayed activation of induction system anti-icing. If the § 33.77 ice ingestion test does not adequately represent the particular airframe installation, then the delayed anti-icing system activation test should be considered. For this condition, the acceptance criteria defined in paragraphs 12 and 13 of this AC should be used. The airframe manufacturer still must consider all potential ice shedding sites (e.g., inboard wing and radome). Similar to the accepted compliance (outlined in Section 2 of this AC) for the § 33.77 ice slab ingestion tests, the use of engine auto-ignition/recovery systems are allowed for showing compliance with the part 25 delayed activation tests, as long as these automatic systems cannot be easily turned off by the flight crew (i.e., a flight crew that inadvertently forgets to turn on the engine anti-ice protection is also likely to have not

selected any other engine protection features, such as continuous ignition, prior to entering the inclement weather). It is important to note the difference in anti-iced inlets versus de-iced inlets. De-iced inlets produce a cyclic shedding of ice from the engine inlet into the engine and typically incorporate as part of their design an inlet particle separator that precludes the ingestion of ice into the core of the engine. It should be noted that the engine's auto-recovery system should not be a compensating design feature utilized to minimize the negative effects of an inadequate particle separating inlet that is not in full compliance with § 25.1093.

b. Damage from testing in non-representative icing conditions. Damage resulting from icing test condition(s) that fall outside of part 25, Appendix C, icing envelopes, or when the airplane flight test is conducted in an abnormal manner and results in excessive ice shed damage, is not considered relevant to compliance with the provisions of § 25.1093.

c. Unacceptable damage. The icing test condition(s) was representative of in-service encounters and the resultant airframe or engine ice sheds caused damage that exceeds the criteria established in paragraph 9.b. of this AC.

17. CONCLUDING REMARKS. Even though applicants may conduct more representative §§ 33.68, 33.77(c), and 25.1093 tests, flight test events may still occur which appear inconsistent. In all likelihood, those results would not be inconsistent when judged in light of the scope, intent, and limitations of the certification testing. Only through reliable instrumentation and photographic evidence can the icing test disparities be fully understood.

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